World Neurosurgery: X 21 (2024) 100268

Contents lists available at ScienceDirect

World Neurosurgery: X

journal homepage: www.journals.elsevier.com/world-neurosurgery-x

Microstructural alterations of major thalamic nuclei in the chronic pediatric spinal cord injured population

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ARTICLE INFO

Keywords:
Spinal cord injury
Diffusion tensor imaging
Thalamus
Pediatrics
Magnetic resonance imaging

ABSTRACT

Background: The brain undergoes reorganization following spinal cord injury (SCI), but little is known about how the thalamus is affected in pediatric SCIs.
Purpose: To characterize microstructural alterations in the thalamus after SCI with diffusion tensor imaging (DTI) metrics.
Methods: 18 pediatric participants with chronic SCI (8–20 years) were stratified using the American Spinal Injury Association Impairment Scale (AIS) into groups: A, B, and C/D. DTI of the brain used a 3 T Siemens Verio MRI using the parameters: 20 directions, number of averages = 3, b = 1000 s/mm^2, voxel size = 1.8 mm × 1.8 mm, slice thickness = 5 mm, TE = 95 ms, TR = 4300 ms, 30 slices, FOV = 230 × 230 mm^2, matrix = 128 × 128, acquisition time = 4:45 min. Diffusion data was processed to generate DTI metrics FA, MD, AD, and RD.
Data analysis: DTI metrics were acquired by superimposing the AAL3 thalamic atlas onto participant diffusion images registered to MNI152 space. We utilized a multiple Mann–Whitney U-test to compare between AIS groups, considering values of $p \leq 0.05$ as significant.
Results: FA, AD, RD, and MD significantly differed in thalamic nuclei between AIS groups A vs B and B vs C/D. Significant nuclei include the right ventral anterior, left intralaminar, bilateral lateral pulvinar, and right lateral geniculate.
Conclusion: Our findings suggest the presence of microstructural alterations based on SCI severity in pediatric patients. These results are encouraging and warrant further study.

1. Introduction

It is established that spinal cord injury (SCI) leads to reorganization in the brain due to physiological responses to neural deafferentation.[1] These brain reorganizations have been associated with gray matter volume atrophy in the primary motor and somatosensory cortices[2–8] along with processes such as neuroplasticity, axon degeneration and demyelination.[3,9] Imaging techniques are frequently used to identify and characterize these changes. Diffusion tensor imaging (DTI) is a modality of magnetic resonance (MR) imaging that offer quantitative diffusion metrics acquired in-vivo which can assess the microstructural integrity of structures such as white matter tracts (WMTs).[10] Several studies have utilized DTI to study spinal cord and brain injuries[11–15] and there is support for DTI as an imaging tool for diagnosing, prognosing, and exploring the efficacy of treatment strategies for SCI.[12,16]

DTI indices, including fractional diffusivity (FA), axial diffusivity (AD), radial diffusivity (RD), and mean diffusivity (MD) elucidate processes such as neurodegeneration, neuroplasticity, and gliosis in both the spinal cord and brain.[17,18] FA quantifies the degree of directionality in diffusion as a measure of anisotropic diffusion, whereas AD evaluates diffusion along the primary axis of a voxel. RD measures diffusion

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https://doi.org/10.1016/j.wnsx.2023.100268
Received 21 January 2023; Received in revised form 12 July 2023; Accepted 28 November 2023
Available online 10 December 2023

Abbreviations

FA	Fractional Anisotropy
AD	Axial Diffusivity
RD	Radial Diffusivity
MD	Mean Diffusivity

occurring perpendicularly along the primary axis of a given voxel, and MD accounts for diffusion in all directions. These indices have the potential to characterize the microscopic properties of tissue, such as the density of axons, their diameters, and their myelination status.[10] In healthy white matter, anisotropic diffusion is typically observed, demonstrating diffusion occurring longitudinally in the direction of axon bundles.[19] Conversely, isotropic diffusion seen in cerebrospinal fluid, gray matter, and compromised white matter tracts, describes diffusion occurring in all directions. Although DTI has traditionally been employed to study WMTs, it can offer valuable information for assessing microstructural changes in gray matter.[20,21] Here, we used DTI to study the effects of SCI on the thalamus which serves as the brain's somatosensory relay.[22]

SCI leads to changes to the structure and functions of the thalamus. For example, the thalamus has been shown to demonstrate hyperactivity immediately after SCI.[23] Functional changes to the thalamus following SCI has also been associated with adverse symptoms such as neuropathic pain[24] or sensory abnormalities during recovery.[25,26] Macrostructural and morphologic changes in the thalamus after SCI include decreased surface area and changes in myelination in sensorimotor nuclei.[27,28] Investigating the effects of SCI on thalamic nuclei may provide further insight into the clinical disposition of patients with SCI long after their injury.

Few studies have investigated microstructural alterations in subcortical structures in the pediatric spinal cord injured population. Here, we obtained DTI scans of pediatric subjects with SCI and compared DTI metrics between grades of SCI severity based on the American Spinal Cord Injury Association impairment scale (AIS)[29] to detect microstructural alterations in 15 thalamic nuclei. Using DTI to characterize these changes can provide insight into the reorganization of the brain after SCI. We hypothesized that there will be differences in DTI indices in thalamic nuclei between AIS classifications indicating microstructural differences between grades of SCI severity.

2. Methods

2.1. Subject recruitment

For this retrospective study, eighteen pediatric participants aged 8–20 years old (mean 16.5 years) with chronic (>6 months post injury) SCI were recruited and evaluated for the level and severity of SCI using the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI).[29] Using the AIS scale, subjects were categorized into three groups: AIS A – absent motor and sensory function below the level of the injury, AIS B – absent motor but partially intact sensory function below the level of the injury, and AIS C and D (C/D) – partially intact motor and sensory functions below the level of the injury. Five subjects were classified as AIS A, nine subjects as AIS B, and four subjects as AIS C/D. Due to low numbers, AIS C and D were combined into one group (AIS C/D). Information on participant age, level of SCI, and cause of SCI can be referenced in Table 1.

This study received approval through the institutional review board and obtained consent and assent from participating individuals and parents/guardians. Criteria for chronic SCI included those with at least six-months since injury and without any neurological changes three months prior to imaging. Other inclusion criteria included subjects who willingly participated in ISNCSCI examination, and were able to tolerate a 45-min-long MRI scan.

Criteria for exclusion included: inability to cognitively participate in the ISNCSCI evaluation and MRI studies; dependence on mechanical ventilation; demonstrating with dysreflexia during the anorectal examination; presenting with implants incompatible with MRI; pregnancy; inability to tolerate MRI studies without sedation; refusal to sign written consent and assent.

2.2. Imaging and processing DTI

Study participants underwent imaging in a 3.0 T Siemens Verio MR scanner with a 12-channel phased array brain coil. T1 and T2-weighted scans of the brain were acquired before diffusion imaging. The following DTI parameters used: 20 directions, number of averages = 3, b = 1000 s/mm^2, voxel size = 1.8 mm × 1.8 mm, slice thickness = 5 mm, TE = 95 ms, TR = 4300 ms, slices = 30, FOV = 230 × 230 mm^2, matrix = 128 × 128, acquisition time = 4:45 min. Following image acquisition, DTI volumes were aligned with the b0 image to correct for motion artifacts and eddy currents using FSL toolbox version 5.0.10 (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSL). The diffusion tensor estimates in each voxel were fit to generate diffusion tensor eigenvalues to calculate the FA map.

Subject images were skull stripped using FSL's BET2 and were placed into standard space via non-linear registration of the diffusion images

Table 1
Demographic information of pediatric subjects involved in this study.

ID	AIS	Age at Enrollment	Age at Injury	Time Elapsed	Sex	Trauma	Mechanism	Neurologic Level
1	A	8.8	4.8	4.8	M	Trauma	MVA	C7
2	B	19.5	N/A	N/A	F	Trauma	MVA	C5
3	B	9.2	1.5	7.7	F	Non-Trauma	Tumor	T4
4	B	18.9	14.2	4.7	M	Trauma	Sports	C9
5	B	18.6	16.7	1.9	M	Trauma	MVA	C4
6	A	15.2	14.3	0.9	M	Trauma	Sports	T7
7	B	20.6	15.9	4.7	M	Trauma	Sports	Indeterminable
8	A	18.9	17.6	1.3	M	Trauma	MVA	T10
9	D	11.4	0.5	10.9	M	Trauma	Fall	C1
10	B	18.5	3.2	15.3	F	Trauma	Fall	T4
11	C	19.3	18.4	0.8	M	Trauma	Sports	C7
12	B	20.3	19.5	0.8	F	Trauma	MVA	T5
13	B	19.4	Birth	19.4	M	Non-Trauma	Fall	T12
14	A	8.8	5.4	3.4	M	Non-Trauma	Fall	L1
15	A	13.9	2.47	11.5	F	Trauma	Sports	T12
16	B	18.4	17.4	0.9	F	Trauma	MVA	T12
17	D	18.2	Birth	18.2	M	Non-Trauma	Birth Injury	C1
18	C	19.1	15.2	4	M	Trauma	Sports	C5

FA, L1, L2, and L3 to MNI152 1 × 1x1 mm^3 space. A multistep non-linear registration was performed using the Symmetric Normalization (SyN) transformation model by running SyN Quick and SyN in succession.[30] Registration with SyN were performed using these parameters: transformation = rigid + affine + deformable syn (3 stages); radius = 4; spline distance = 26; gradient step size = 0.1; precision type = double; use histogram matching = false; collapse output transforms = 1; Fix random seed to an int value = system time. Visual quality checks were performed to ensure proper alignment of atlas based structures to their approximate locations in subjects after registration.

Region-of-Interest (ROI) analysis of thalamic nuclei involved aligning 15 major thalamic nuclei from the AAL3 thalamic atlas to subject images registered to MNI152 space. DTI metrics FA, AD, RD, and MD were acquired in every nuclei for each subject. To supplement our primary analysis, the described process was repeated for brain white matter tracts using the Johns Hopkins University (JHU) white matter tract atlas. Statistical analysis involved a Mann–Whitney U Test to compare diffusion indices between AIS groups with the threshold for significance set at $p \leq 0.05$.

3. Results

Three comparisons were performed between AIS groups (AIS A vs AIS C/D, AIS A vs AIS B, and AIS B vs AIS C/D). Chi square analysis showed no gender differences, X^2 (1, $p > 0.05$) and a one-way anova with Tukey–Kramer multiple comparison tests showed no age differences between AIS classifications ($p > 0.05$). Analysis of mean DTI metrics FA, AD, RD, and MD determined differences between AIS groups suggesting the presence of microstructural alterations in thalamic nuclei and cerebral white matter tracts in pediatric subjects with SCI. In the thalamus, right ventral anterior nucleus (tAV), left intralaminar nuclei (tiL), right lateral geniculate nucleus (LGN), and the left and right lateral pulvinar (PuL) nuclei demonstrated microstructural alterations. In these regions, differences in diffusion indices of FA, AD, RD, and MD were observed between AIS groups. Additional analysis of cerebral WMTs also demonstrated microstructural alterations in several ROIs. ROIs with significantly different diffusion metrics between AIS classifications are presented below (Table 2 and Figs. 1–3).

Table 2
Significant ROIs demonstrating differences in DTI metrics between grades of SCI severity based on AIS classification.

AIS	Thalamic Nuclei	Abbrev.	Metric	Result	p-value
A vs B	Right Ventral Anterior	R. tAV	AD	A < B	0.042
			MD	A < B	0.019
			RD	A < B	0.029
	Left Intralaminar	L. tIL	AD	A > B	0.013
B vs CD	Left Lateral Pulvinar	L. tPuL	AD	B < CD	0.034
	Right Lateral Pulvinar	R. tPuL	AD	B < CD	0.034
	Right Lateral Geniculate	R. LGN	FA	B > CD	0.05
AIS	**White Matter Tract**	**Abbrev.**	**Metric**	**Result**	**p-value**
A vs B	Left Cingulum Cingulate Gyrus	L. CCG	FA	A < B	0.012
	Right Cerebral Peduncle	R. CP	FA	A < B	0.012
	Splenium of Corpus Callosum	Spl. CC	FA	A < B	0.029
	Left Corticospinal Tract	L. CST	FA	A < B	0.042
	Left Superior Fronto-Occipital Fasciculus	L. SFOF	FA	A < B	0.042
	Pontine Crossing Tract	PCT	AD	A > B	0.042
	Left Cingulum Cingulate Gyrus	L. CCG	AD	A < B	0.042
	Left Posterior Limb of Internal Capsule	L. PIC	MD	A > B	0.042
	Right Sagittal Stratum	R. SST	MD	A > B	0.042
	Left Uncinate Fasciculus	L. UF	MD	A > B	0.042
B vs CD	Right Retrolenticular part of the Internal Capsule	R. RTIC	AD	B > CD	0.011
A vs CD	Right Cingulum Cingulate Gyrus	R. CCG	FA	A < CD	0.016
	Left Cingulum Cingulate Gyrus	L. CCG	FA	A < CD	0.032
	Fornix (Column and Body)	Fornix (C/B)	MD	A < CD	0.032
	Right Sagittal Stratum	R. SST	MD	A > CD	0.032
	Pontine Crossing Tract	PCT	AD	A > CD	0.016
	Right Anterior Limb of Internal Capsule	R. AIC	AD	A < CD	0.016
	Right Retrolenticular part of Internal Capsule	R. RTIC	AD	A > CD	0.032
	Right Sagittal Stratum	R. SST	RD	A > CD	0.016

Abbreviations: FA = Fractional Anisotropy; AD = Axial Diffusivity; RD = Radial Diffusivity; MD = Mean Diffusivity.

4. Discussion

Here, we found microstructural alterations in thalamic nuclei and cerebral white matter tracts based on the severity of SCI. Although our findings are clinically non-specific, given that DTI indices alone cannot definitely identify a certain pathologic or adaptive process, these microstructural changes suggest that there may be neuronal responses after deafferentiation leading to brain reorganization. To our knowledge, this is the first study to use DTI for investigating thalamic changes in the pediatric SCI population.

SCI predominantly results in the loss of sensorimotor control, yet patients over time can also develop other sequalae such as pain[31,32] and depression.[33] Furthermore, SCI often culminates in detrimental long-term outcomes, contributing towards reductions in life expectancy.[34,35] These adverse developments underscore the progressive consequences of SCI, which accentuate the need for markers that can detect neurodegenerative changes or even therapeutic progression with treatment. Despite significant evidence for neuronal reorganization in the brain following SCI, knowledge regarding the localization of these effects and their clinical implications remain limited. This is particularly important in pediatric patients who will spend their most of their lives managing and adapting to their SCI.

4.1. Correlating diffusion metrics with microstructural alterations in white and gray matter

As mentioned, FA refers to the degree of directional diffusion or anisotropy, which is better exhibited in white matter tracts compared to gray matter. Decreasing FA values can reflect WMT degeneration through processes like axon damage, fiber loss, and demyelination which has been demonstrated in WMTs in SCI patients.[3,13,14] In gray matter, FA alterations may involve changes to passing WMTs, neuron and dendrite number, dendrite connections, tissue compaction, and gliosis.[36] AD reflects axonal density or caliber, and RD reflects axonal or myelin integrity.[19] Specifically, AD has been shown to change with factors that affect diffusion along a straight path parallel to brain fibers which means it can increase with decreased axonal density or caliber.[37] Regarding RD, values are negatively correlated with myelin status and characteristics like myelin sheath thickness which can effect perpendicular diffusion from the fiber axis.[37] MD reflects diffusion in all directions and thus can increase with disruptions to tissue integrity that breakdown barriers to diffusion.[10] As MD disregards the directionality of diffusion, it has been viewed as a stronger biomarker for microstructural alteration in gray matter.[38] DTI imaging of subcortical gray matter structures affected by Alzheimer's disease, epilepsy, Parkinson's disease, and alcohol dependency have associated increased MD with cellular loss, atrophy, and expansion of extracellular space.[20,39–41]

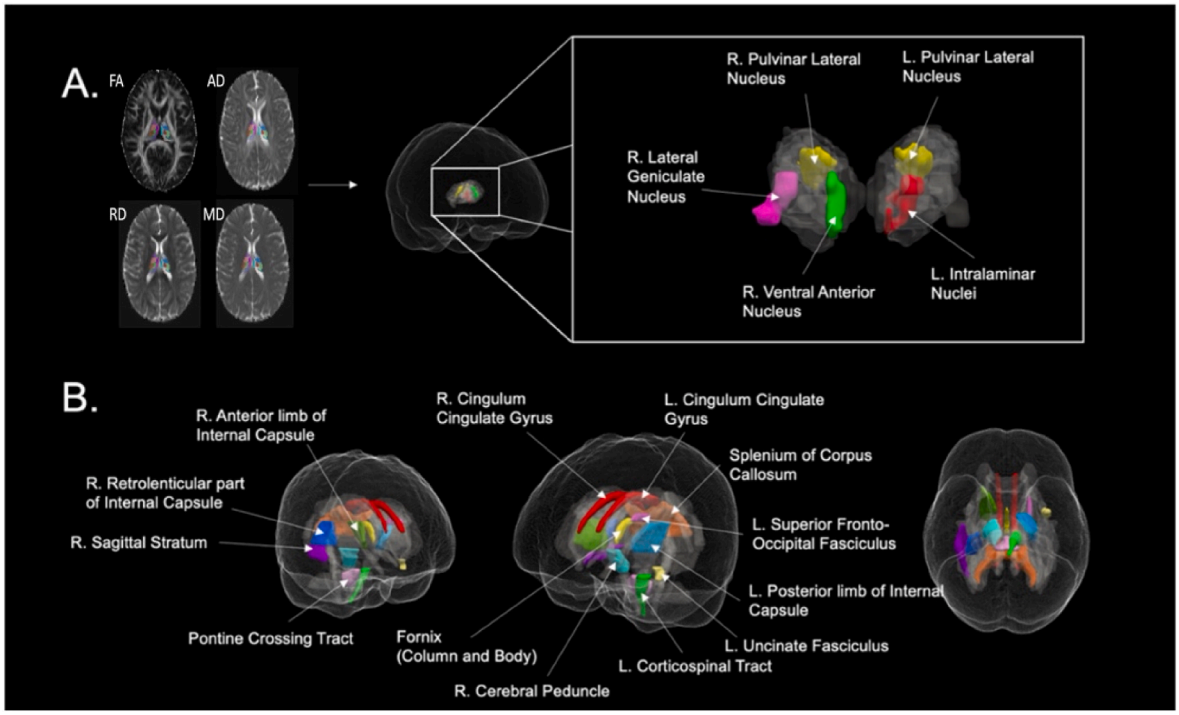

Fig. 1. (A) Overlay of AAL3 Thalamic Atlas over DTI images to extract diffusion indices for major thalamic nuclei. Shown are four thalamic nuclei found to have significantly different diffusion indices between different grades of SCI (B) White matter tracts from the JHU WMT atlas with significant differences in diffusion indices between different grades of SCI injury.

Oppositely, studies using DTI in gray matter mentioned decreased MD may result from processes that reduce water diffusion such as cellular swelling or increased cellular density.[42–44] Although the diffusion metrics are nonspecific, the changes observed in thalamic nuclei in pediatric subjects with SCI may be clinically relevant and lay the foundation for further studies.

4.2. Microstructural alterations in major thalamic nuclei

The thalamus functions to relay and regulate sensorimotor information to the cerebral cortex and is involved with all sensation except for olfaction.[22] Differences in diffusion indices in the reported thalamic nuclei may represent adaptive or maladaptive reorganization following SCI.

The ventral anterior nucleus (VA) is part of the motor thalamus and relays information involved in motor control, specifically information related with the planning and execution of motion.[45] Huber et al observed both contraction and expansion in surface area in inferior and superior parts of the VA, respectively.[27] Thus, decreased AD, RD, and MD in the right VA in AIS A versus AIS B could indicate neuroplastic changes related to compensating for the loss of motor function after SCI.

The pulvinar nucleus (Pu) has been associated with coordination of cortico-subcortical connections as well as various facets of cognition such as orientation to attention and sensory stimuli, the recognition of emotions, and motor actions.[46] However, the clinical implications for microstructural alterations observed bilaterally in the lateral pulvinar are unclear as the functional connectivity of the pulvinar is not well defined. Geudj and Vuilleumier used resting state fMRI to delineate functional connectivity based on anatomic divisions of the pulvinar and found that the anterior and lateral divisions are involved with roles pertaining to action and attention.[46] Prior studies have observed alterations to the Pu after SCI. Surface area contractions have been observed bilaterally in the lateral and medial Pu in SCI patients.[27] Following complete SCI, Karunakaran et al found both increases and decreases in the functional connectivity between the thalamus and cortex.[26] This study found decreased thalamo-cortical connectivity from areas of the left pulvinar and reported a negative relationship with injury duration and the connectivity between the visual, motor, and secondary somatosensory cortices with pulvinar nuclei bilaterally.[26] Thus, decreased AD in the left and right lateral pulvinar could also indicate neuroplastic changes reflecting thalamic reorganization.

The intralaminar nuclei (IL) consist of smaller nuclei with inputs from the reticular formation, spinothalamic tract, and trigeminothalamic tracts to other thalamic nuclei and the cerebral cortex.[22] Functions of the IL include regulation of other thalamic nuclei and the level of consciousness and alertness.[22] Probabilistic tractography of connections from the IL has shown a high degree of connectivity with brain areas associated with arousal, attention, and sensorimotor functions.[47] Increased AD in IL may represent a decrease in axonal density related to neuroplasticity or neurodegeneration.

The lateral geniculate nucleus (LGN) is well known to be involved in the visual pathway as a relay between the retina and the primary visual cortex.[48] This study found that FA increased in AIS B compared to AIS C/D which indicates alterations in to gray matter structure or WMTs found throughout the LGN following SCI. Rulesh et al used human in-vivo and in-vitro studies to conclude that ferritin present in gray matter can influence DTI metrics, which can increase FA.[36] Relatedly, iron accumulation in the brain has been associated with neurodegenerative conditions like Huntington's disease and physiologic aging.[36,49] Increased FA in the thalamus could represent changes to gray matter structure, possible related to iron deposition after a SCI. Changes in the LGN may reflect alterations in visuospatial processing common to patients with SCI.[50] Lam et al studied proprioceptive defects after SCI and reported that ambulatory individuals with SCI rely more on vision when tasked to overcome obstacles.[51] Thus, changes in the LGN may be associated with increased reliance on visual input for coordination.

4.3. Microstructural alterations reported in cerebral white matter tracts

In general, subjects with a more severe classification of SCIs showed

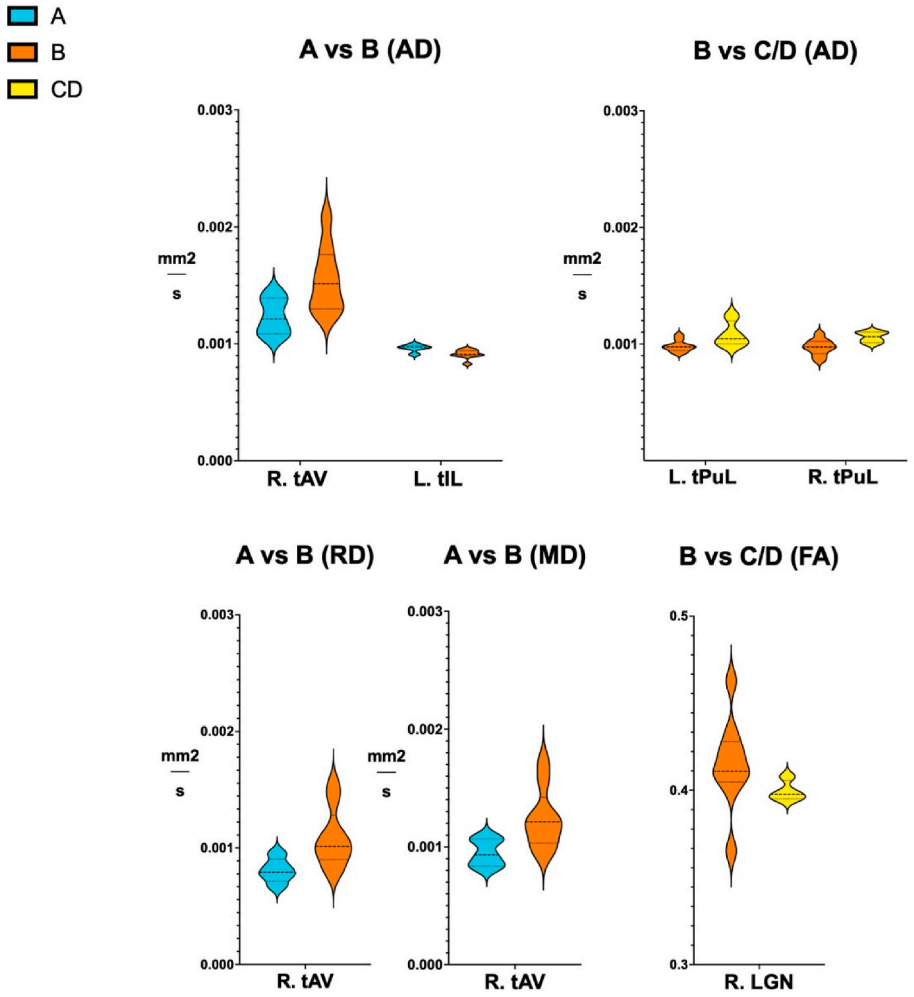

Fig. 2. Violin plots displaying comparisons of DTI ROI analysis between severity of SCI based on AIS classification. Shown are thalamic nuclei demonstrating significant differences in diffusion metrics suggesting the presence of microstructural alterations.

decreased FA and increased MD in cerebral WMTs. These findings are consistent with prior literature in subjects with SCI.[3,13,14] Additionally, both increases and decreases in AD and RD were discovered, although the changes are nonspecific. Microstructural alterations within cerebral white matter tracts indicate a decrease in structural integrity of affected WMTs possibly due to a demyelinating or degenerative process, as demonstrated by the decreased FA and increased MD.

Categorically, microstructural alterations were found in various WMTs associated with motor, sensory, visual, and behavioral pathways. This was expected as a SCI impacts efferent and afferent pathways which leads to changes in both the structural and functional connectivity of the sensorimotor network.[52] Interestingly, the thalamus is known to possess reciprocating connections with areas of the cortex which also pass through the anterior, posterior, and retrolenticular limbs of the internal capsule,[53] where AD decreased in AIS B versus C/D and MD increased in AIS A versus B, respectively. The cause of change in AD is uncertain, but increased MD may suggest decreased myelination or degeneration of connections from the thalamus after SCI.

4.4. Limitations

This study experienced some limitations that may have influenced our findings. We first discuss limitations in our methodology. Notably, the lack of a control group means that alterations in diffusion metrics were not relative to typically developed participants. Low subject number also lead to inconsistent numbers of AIS classifications consisting of 5 AIS A, 9 AIS B, 4 AIS C/D. Furthermore, due to concern for low statistical power, post-hoc analysis was not performed. Another limitation in methodology was the alignment of atlas-based ROIs to patient diffusion images of a different spatial resolution. We did not fully account for partial volume effects, but they are presumed to be minimal as the volumes of significant ROIs were relatively large. Nonetheless, partial volume effects may have affected the accuracy of measured DTI metrics.

As SCI is a dynamic process, a number of temporal factors must be discussed, such as the variable age of participants (8–20 years). Linear regression showed no correlation between age and diffusion scalars, although this may not entirely rule out the effect of differences in neurologic development across age groups. Age may have also affected the initial evaluations for AIS classification and neurological tests requiring subject participation. Other temporal factors we did not fully consider include the age of subjects at the time of injury and the time interval between injury and subject participation. Additionally, we did not account for variables such as the mechanism of SCI and injury level. These factors may have influenced the degree of changes in diffusion metrics due to differences in nature of the SCI and the stage of neurologic development at the time of injury as well as the time frame for which neurologic changes may have occurred following SCI.

5. Conclusion

This study used DTI to demonstrate the presence of microstructural

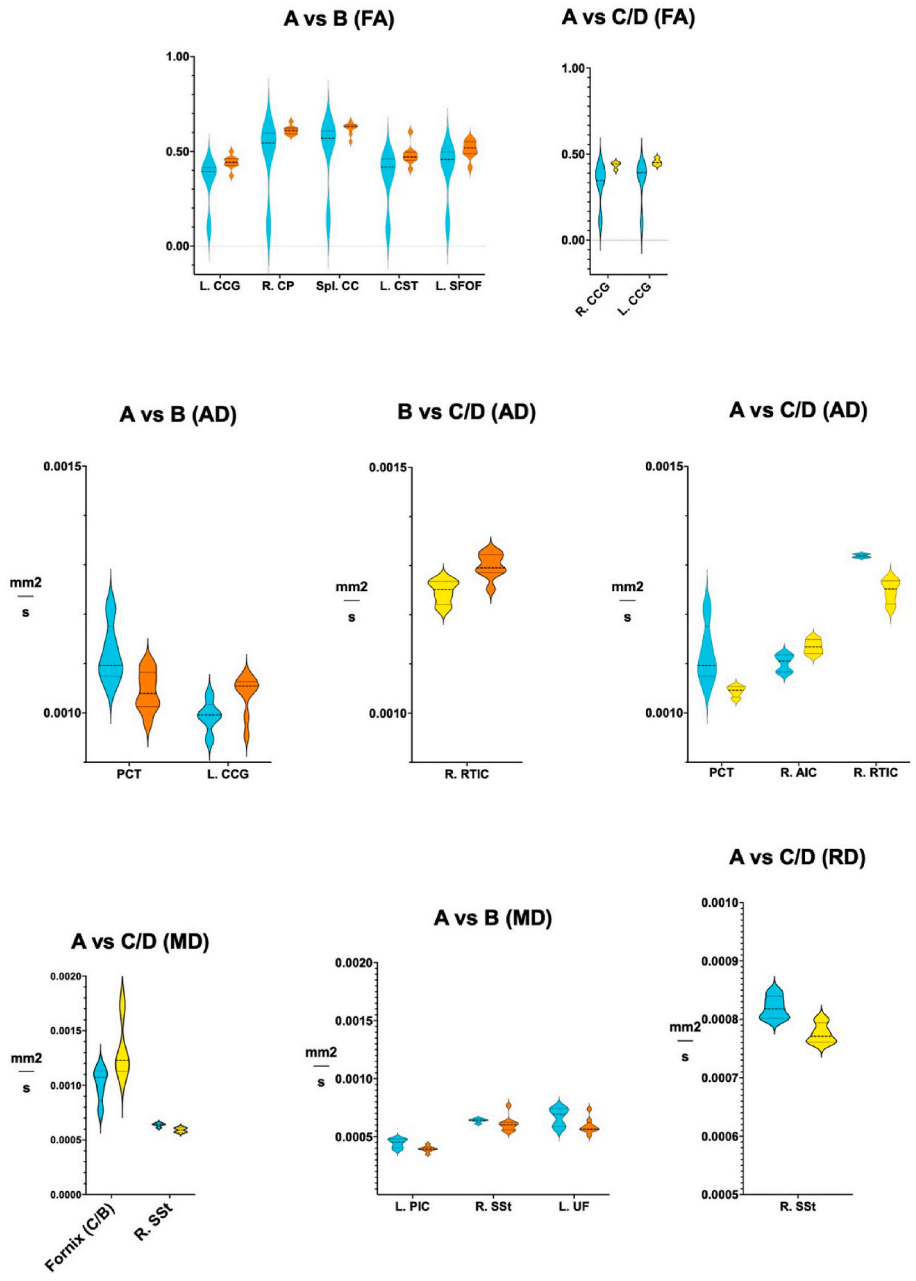

Fig. 3. Violin plots displaying comparisons of DTI ROI analysis between severity of SCI based on AIS classification. Shown are white matter tracts demonstrating significant differences in diffusion metrics suggesting the presence of microstructural alterations.

alterations in a few thalamic nuclei and cortical white matter tracts between AIS classifications in pediatric subjects with chronic SCI. Although our findings are limited and non-specific, they suggest that the microstructural integrity of subcortical structures can vary with the severity of injury. DTI indices may provide prognostic utility in those affected by SCI and potentially allow for targeted therapy strategies to patients based on the localization of microstructural changes. Our findings are encouraging and warrant further investigation with improved parameters such as the inclusion of control subjects, increased participant numbers, higher resolution imaging, and further exploration of using diffusion imaging biomarkers in the clinical practice for SCI.

CRediT authorship contribution statement

K. Kang: Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **K. Fleming:** Formal analysis, Data curation, Investigation. **A. Sathe:** Writing - review & editing, Investigation. **J. Muller:** Writing - review & editing, Investigation. **J. Harrop:** Supervision, Methodology, Writing - review & editing, Data curation, Investigation. **D. Middleton:** Data curation, Writing - review & editing, Formal analysis. **J.E. Heller:** Writing - review & editing. **A. Sharan:** Writing - review & editing, Supervision. **F. Mohamed:** Writing - review & editing, Formal analysis, Supervision, Data curation, Funding acquisition. **L. Krisa:** Investigation, Data curation, Writing - review & editing, Funding acquisition. **M. Alizadeh:** Writing - review & editing, Supervision, Investigation, Methodology, Data curation, Conceptualization, Formal analysis, Funding acquisition, Software, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper

Acknowledgments

The study was funded by the Shriners Hospitals for Children Research Grant 8509.

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Diffusion Tensor Imaging (DTI) Abbreviations

FA =: Fractional Anisotropy
AD =: Axial Diffusivity
RD =: Radial Diffusivity
MD =: Mean Diffusivity

Thalamic Nuclei Abbreviations

tAV =: Ventral Anterior
tIL =: Intralaminar Nuclei
tPuL =: Lateral Pulvinar
LGN =: Lateral Geniculate Nucleus

White Matter Tract Abbreviations

CCG =: Cingulum Cingulate Gyrus
CP =: Cerebral Peduncle
Spl. CC =: Splenium of Corpus Callosum
PCT =: Pontine Crossing Tract
SST =: Sagittal Stratum
SFOF =: Superior Fronto-Occipital Fasciculus
UF =: Uncinate Fasciculus
CST =: Corticospinal Tract
PCT =: Pontine Crossing Tract
Fornix (C/B) =: Fornix (Column and Body)
AIC =: Anterior Limb of Internal Capsule
PIC =: Posterior Limb of Internal Capsule
RTIC =: Retrolenticular part of Internal Capsule